

Fermi National Accelerator Laboratory
Technical Division
P.O. Box 500 MS 316
Batavia, IL 60510
Fax: (630) 840-3756 Ph: (630) 840-3411

Trip Report
Travel to Delhi, Calcutta, Indore, Mumbai India
Shekhar Mishra

Facilities Visited:

University of Delhi, Delhi
Variable Energy Cyclotron Center, Kolkata
Nuclear Science Center, Delhi
Center of Advanced Technology, Indore
Tata Institute of Fundamental Research, Mumbai

Abstract:

The main purpose of this trip was to attend the Indian Particle Accelerator Conference (INPAC'2005) that was held in Kolkata (Calcutta), India. Since Dec 02 there has been an ongoing effort to setup India-USA collaboration on accelerator physics, technology and expanding the High Energy Physics collaboration. There were several meetings to start a formal discussion on Accelerator R&D collaboration. We view that the initial discussions are at a stage now that formal discussions can start.

Trip Analysis:

On this trip, the US scientists – Vinod Bharadwaj (SLAC) Shekhar Mishra (Fermilab), Deepak Raparia (BNL), Andy Sessler (LBNL) – visiting India continued the discussions about a formal India-USA collaboration on various accelerator physics and technology topics in New Delhi, Kolkata, Indore and Mumbai. In Delhi the US scientists met with Professor Ramamurthy, the Secretary of Department of Science and Technology (DST), for two hours and in Mumbai, they met with Dr. Kakodkar, the Secretary of the Department of Atomic Energy (DAE), for three hours. DST is the equivalent of the US NSF and DAE is the equivalent of the US DOE. In addition I was invited at the last minute to meet with Dr. A. P. J. Abdul Kalam, the President of India. *This is a remarkable level of interest from India for this collaborative effort.* In Kolkata the discussions were with attendees at the conference and senior staff of VECC and in Indore they were with the senior staff of the Centre for Advanced Technology. A formal agreement is being generated, the effort being led by Shekhar Mishra from Fermilab and Dr. Vinod Sahni from CAT India.

There has been an ongoing effort to set up a relatively formal US-India collaboration on various accelerator and related topics. The history so far is

- Start of the discussion in Dec. 02 with Prof. Ramamurthy, Secretary of Department of Science and Technology (DST).
- Interaction Meeting on Linear Collider and Neutrino Physics was held in New Delhi, Nov. 03. (Attended by 19 US and 70 Indian scientists). This was followed by visits to Centre for Advanced Technology, Indore (CAT) & Tata Institute for Fundamental Research, Mumbai (TIFR).
- Indo-US working group was established by Prof. Ramamurthy and Prof. Witherell, Director of Fermilab.

- Working group met at Fermilab in Aug. 04 and a program of collaboration was discussed. Attached is the collaborative document from that meeting as Appendix-I-05.

We met with Prof. Ram Shivpuri of the University of Delhi just after our arrival in Delhi, India. He and Prof. Naba K. Mondal, TIFR have been involved in these collaborative discussions between USA and India since the very beginning. They are also our collaborator in the D0 experiment at Fermilab. We discussed with him the progress that has been made in our collaboration development and the agenda of this visit.

On Feb. 28th afternoon the US visiting team met with Prof. V. S. Ramamurthy and informed him of the progress in last one year since our Nov. 03 meeting in New Delhi. The slides from this meeting are attached as an Appendix II-05. India is very keen in collaborating on the Accelerator R&D and would like to get the young scientists and engineers involved.

On March 1st we traveled to Kolkata, India to attend the InPac-2005. Although this conference is called "Indian Particle Accelerator Conference", more than a dozen foreign scientists attend this conference from Asia, Europe and USA. This significant foreign participation is mainly due to India's developing technology base and growing economy of India. India is an associate member state with CERN. India has made very valuable contributions to LHC accelerator. Indian scientists have been collaborating at many US laboratories. The talks from the non-Indian speakers were on large projects such the linear colliders, proton accelerator and x-ray FELs with pleas from the speakers for Indian collaboration on these projects. These pleas were based on advances in the state of technology in India and on the potential cost saving in the price tags of large projects by the efficient use of Indian laboratories and industry. I made the presentation on the International Linear Collider R&D based on the Superconducting RF technology. This technology was recommended by the ITRP. Prof. Jean-Pierre Delahaye of CERN urged India to continue its collaboration with CERN and work on the CLIC technology for the Linear Collider. I and Deepak Raparia of BNL presented the Fermilab Proton Drivers and BNL Super Neutrino projects. The Fermilab's proton driver proposal received considerable discussion during and after the meeting as it is similar to Indian proton accelerator program. Vinod Bharadwaj, SLAC presented a talk on the Design Issues for the ILC Positron Source. Prof. Andy Sessler, LBNL was scheduled to give a talk on the 4th Generation Light Source, but he could not give that talk at InPac due to illness. He gave this talk during our visit to CAT.

Private discussions among the foreign visiting scientists centered around how to get Indian scientists involved on these large accelerator projects i.e. ILC. We all felt that India's technical capabilities are at par with major labs in Asia, Europe and USA and India is becoming an economy power in Asia. We were impressed with the quality and quantity of papers that were presented at the conference. Prof. Shin-ichi Kurokawa, KEK and present chair of ACFA requested that the visiting foreign scientists should write a joint report on their assessment of Indian Accelerator Technology. He and I viewed that such a report will help us get India the attention it deserves from the International community.

During our visit to VECC we got a tour of the accelerator facilities there. VECC has a room temperature cyclotron operating since 1978 and is getting ready to commission a superconducting cyclotron, Fig. 1. They have built this with Indian industry with very minimal help from European Industry. VECC is also constructing a Radioactive Ion Beam facility and performing preliminary studies regarding the Accelerator Driven System using cyclotron. Fig. 2 shows a four-rod type Radio Frequency Quadrupole (RFQ) Linac that has been designed for an input energy of 1.0 Ke/u and $q/A > 1/16$. The output energy will be ~ 86 keV/u for a 3.2 meters long 35 MHz structure.



Fig. 1: VECC Cyclotron Magnet with Cryostat Installed in it.



Fig. 2. The RFQ build for the RIB facility.

I visited the Nuclear Science Center, New Delhi. The center has a 15UD Pelletron Accelerator and the accelerator augmentation program of superconducting linac and high current injector. During our tour we visiting the Superconducting Linac, Superconducting cavity fabrication facility, High current Injector and the Low Energy Ion Beam Facility. The Pelletron accelerator at NSC is capable of accelerating ions having mass up to 40 amu above coulomb barrier. To augment the beam energy above Coulomb barrier for mass up to 100 amu, a booster SCRF linear accelerator is being instale. He linac will consist of one superbuncher cryostat consisting of a single Quarter Wave Resonator (QWR), three Linac cryosats, each consisting of eight QWRs and a solenoid as focusing device and a rebuncher cryostat consisting of two QWRs. The frequencies of these SCRF cavities are similar to those of the RIA project being developed in USA.

NSC has developed a SCRF cavity fabrication laboratory for design, fabrication and testing of the SCRF cavities. Fig 3. shows the QWR before going in cryostat and its performance. Fig. 4 show the electron beam welding facility and Fig. 5 shows the 1300 deg c furnace crucial for production of these cavities. There electron beam welding machine can be used to weld ILC and PD cavities. These hardware have been build by Indian industries at considerable smaller cost than US vendors.

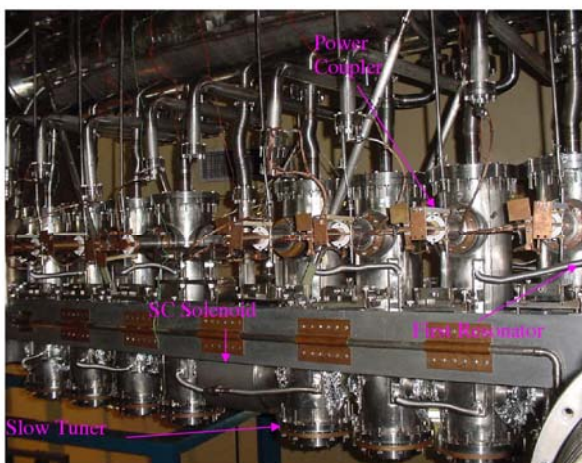


Fig. 3. SCRF QWR cavities and its performance.

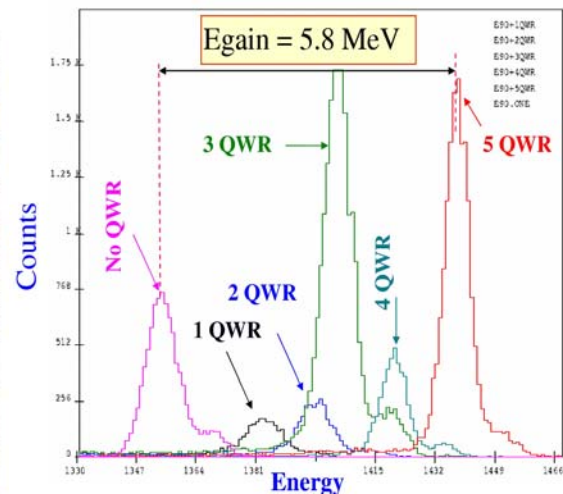




Fig. 4 Electron Beam Welding Facility



Fig. 5. 1300 deg C furnace for cavity processing

A collaboration with NSC in development of Proton Driver cavities can be discussed. Soon they would finish producing cavity for NSC use. Another possibility is to get these industries to build these facilities for Fermilab.

During our visit to CAT we presented the same talks as we did at VECC. Many of the CAT accelerator scientists and engineering staff could not travel to Kolkata. Dr. Chaddah, CAT presented a talk outlining a R&D program on newer materials, their deposition methods, as well as exploiting the possibilities of superheating etc. as proposed by Dr. Hasan Padamsee. Dr. S. Kotaiah, CAT presented a status talk of the 2.5 GeV Synchrotron Radiation Source Indus-2. Indus-2 is a third generation light source having critical wavelength of 1.98 Å. The whole accelerator complex has been put together and commissioning is about to start after the safety and operational approval. Only the RF cavity in this accelerator is not made in India. The magnets, power supplies, vacuum chambers, controls etc are either produced at CAT or fabricated in collaboration with Indian industries. The quality of workmanship is excellent. Fig. 6 shows the injection and RF area of the Indus-2.



Fig. 6 Indus-2 Injector and RF area.



CAT is also developing a Compact ULtrafast Tera-Hertz Free Electron Laser (CUTE-FEL) and its application laboratory. They have build an undulator to go downstream of a electron accelerator. Fig. 7 shows one of two sections of the CUTE-FEL undulator: planar, PPM, 5 cm period, 25 periods. Gap variable from 33-100 mm. Maximum undulator parameter = 0.8.

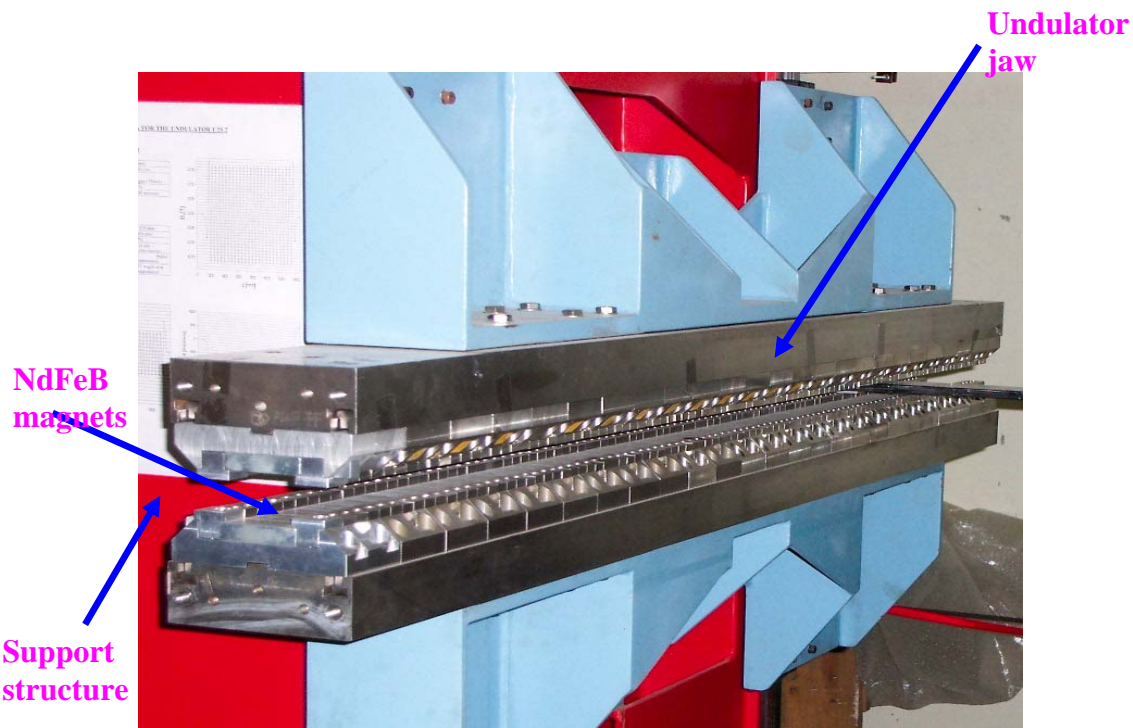


Fig. 7. CUTE-FEL Undulator

At CAT we also heard the developments with India-CERN LHC program. India has build the MCS and MCDO corrector magnets for the main dipole magnets for LHC. It is designed to correct the systematic field errors of the LHC Main Dipole and it shares the same cryostat. India has also build the Quench Protection system power supply units, stands for the magnets etc.

We were also told about the CAT program to build a Spallation Neutron Source. This is yet another area where Fermilab Proton Driver and CAT can collaborate.

At Mumbia we met with Dr. Anil Kakodkar and I presented the same talk we had given in Delhi that is attached as Appendix I. This presentation was very interactive as Dr. Sahni, Director of CAT, Prof. Naba Mondal, TIFR and Spokesperson of the Indian Neutrino Observatory (INO) were also present. The discussion centered around collaboration on the following topics: International Linear Collider, High Intensity Proton Linac for Neutrino Physics and 4th Generation Light Source. India's view was that they would like to collaborate on international projects like Linear Collider provided they could develop a physics and accelerator program of their own with similar technology. The discussion was of an open collaboration. India views the Proton Linac and 4th Generation light source to have practical application to its scientific program. A desire to aim a high intensity neutrino beam towards the INO detector was discussed. We pointed out that it could be important to invite international collaboration to INO. Indian side requested that US help hold an accelerator school in India to train more people in a cost effective manner. They also requested help in commissioning Indus-2 if it becomes necessary. The level of funding needed for ILC R&D was discussed. One guess is that it could be of the level of India's contribution to LHC. Indian side felt that this is not a significant amount. This meeting ended with a set of action items for the scientists at both end to discuss with their managements. We are planning to meet around PAC2005 in USA to finalize this so that some management discussion can take place.

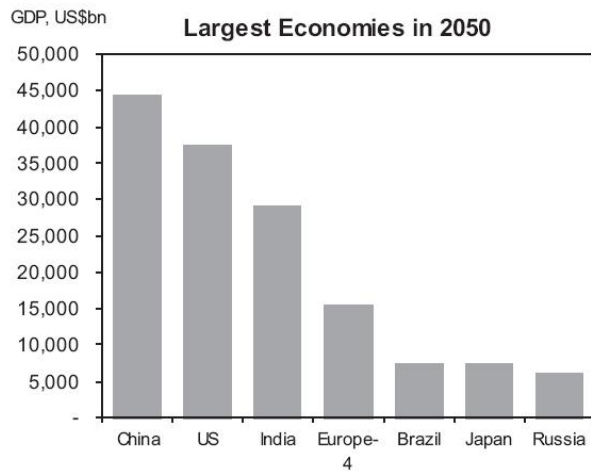
Most of the US scientists returned to USA after Mumbia. I returned to Delhi to spend some time at University of Delhi. University of Delhi has been working with Fermilab on the Main Linac Simulation. Kirti Ranjan from Delhi is stationed at Fermilab and Ashutosh works from India. While in Delhi Prof. Shivpuri arranged for a meeting with the President of India. Prof. Shivpuri had kept his office informed of the developments in last 3 years. This meeting was not planned from before and I am humbled with the great respect the president of India gave me. Dr. Kalam was very much interested in learning about Indian scientist participation at Fermilab. I described to him our accelerator and HEP program. He was keen to learn about the International Linear Collider and how India can help. I

also showed him some papers Indian students have been working at Fermilab. We talked about training the younger generation of scientists and how these sciences can help the common person. His vision for India in 2020 has been a technology India, where life of people is touched by modern technology. I told him about the growing potential of India to significantly contribute in the field of science and technology. He asked me to write him a letter (less than one page) describing how India can contribute and collaborate on these projects.

I returned to USA on the night of March 11th. This trip was one of the most hectic trips I have taken. We visiting many laboratories gave many talks and discussed collaboration with Indian scientists on several accelerator projects. I have been pushing this collaboration for last 3 years, it appears that we are getting close to have something done.

The Indian Economy:

The Indian economy is very dynamic, expanding at about 8% per year and is expected to do so for the foreseeable future.



GS BRICs Model Projections. See text for details and assumptions.

Some projections – see the figure from a Goldman-Sachs research report <http://www.new-frontiers.org/classicdocs/thebricsreport.pdf>, – expect that in 2050 the Indian economy to be the third largest in the world, just behind the US. Indian labs and industry seem capable of producing a very high level of technology and their capabilities are growing. It is this fact that suggests that collaboration in accelerators would be beneficial for both India and the USA.

Summary of Indo-US Accelerator R&D Working Group Meeting Fermilab, Aug 5th-6th 2004.

Editor: Shekhar Mishra, Fermilab
Vinod Sahni, Center of Advanced Technology
8/28/04 (last edited by V.C. Sahni 9/4/2004)

Although the full Indian contingent could not reach, the first planned meeting of the Indo-US Accelerator R&D working Group was held at Fermilab on Aug 5-6 2004. Scientists from Fermilab, SLAC, Jefferson Lab (Jlab), Argonne (ANL) and Brookhaven National (BNL) Laboratories met with the scientists from India. All the US members of the Indo-US Accelerator R&D working group participated in the meeting. A full list of people who attended the meeting and agenda is attached as Appendix-I and II. The topics that were discussed during US scientists visit to India in Nov 2003 and possible areas of collaboration between India and USA as discussed prior to this meeting is attached as Appendix-III.

The two days presentations and discussions centered on how to proceed with the collaboration on accelerator, detector and neutrino physics. The group heard presentations on U.S. accelerator activities at Fermilab, SLAC and ANL. There were focused accelerator R&D presentations on International Linear Collider (ILC), Fermilab Superconducting Proton Linac, Rare Isotope Accelerator, grid computing at Fermilab and emerging grid computing in India. The past, present and future Indian accelerator program and its strength in accelerator development was also presented. There were group discussions on the ILC detector and neutrino physics experiments collaborations in both countries.

The group discussed the next step to develop this collaboration. It was concluded that the most effective way to initiate the collaboration would be exchange of scientists and engineers.

- US laboratories can host Indian scientists as a start of scientific exchange and can initially accept say upto two Indian scientists at each of the collaborating US laboratories. The project and details of the visiting persons would be decided by mutual interest. It is expected that this will be an avenue to involve working level persons and hence most of these visitors will be junior scientists and engineers. It was agreed that initial period of visit should be say for minimum of 6 months each and there should be some overlap between rotating scientists.
- US scientists will visit Indian laboratories for specific topics of interest to develop collaboration and building contacts, for example
 - Commissioning of Indus-II
 - Review of Indian accelerator projects
 - Holding Indo-US Accelerator Schools
 - Participation of US scientists in Indian conferences

Funding for the travel and stay of these scientists in the two countries was discussed. At present the US laboratories do not have funds to support the scientific exchange between India and USA. US laboratories can provide office space, administrative and computing support, but sources for living and travel expenses have to be found. It was discussed that

this Indo-US Accelerator R&D working group look into several sources of funding to support these visits.

There are two existing Indo-US agreements for scientific exchanges that can be used to fund this collaborative research. It is also possible that India may have other funding mechanism to support these activities.

1. The Indo-US science Forum
2. India-DST and US-NSF Program for collaborative research project.

Action Item: We will write three proposals to be submitted to these funding agencies.

1. International Linear Collider is the ultimate goal of the accelerator R&D collaboration. It is realized that in achieving this goal we must collaborate on other accelerator projects. We will submit a proposal to Indo-US Science Forum to support travel related to the Accelerator R&D. PI: Shekhar Mishra, USA and Vinod Sahni, India
2. India has already made significant contributions to the High Energy Physics Detector R&D and construction as well as their installations in some labs in USA. India could therefore naturally participate in a International Linear Collider Detector collaboration and related R&D. We will submit a proposal to DST-NSF to support this activity. PI: Harry Weerts, USA and , (nominee to be decided by) India.
3. Fermilab, BNL and many Indian institutions have considerable interest in Neutrino physics. We will submit a proposal to DST-NSF to support this activity. PI: Doug Michael, USA and (nominee to be decided by) India.
4. Fermilab and BARC/TIFR teams in India have considerable interest in astroparticle physics of which gamma ray astronomy is an important part. There is an opportunity to forge new partnership especially in the context of planned Indian Gamma Ray Telescope at Hanle, Ladakh. PI:,USA and R Koul, India.

Appendix-I: List of Scientists who attended the first meeting of the Indo-US Accelerator R&D Working Group Meeting.

USA

Fermilab

Steve Holmes, Associate Director of Accelerator
Hugh Montgomery, Associate Director of Research
Robert Kephart, Division Head, Technical Division
Vicky White, Division Head, Computing Division
Paul Czarapata, Associate Division Head, Accelerator Division
William G. Foster, Head, Proton Driver R&D
Shekhar Mishra, Head, Linear Collider R&D
Andreas Kronfeld, Senior Scientist, Theory Department
Harry Weerts, Guest Scientists, Linear Collider Detector R&D

SLAC

David Burke, Assistant Director, Linear Collider

ANL

Kwang-Je Kim, Senior Scientist, Leader of Coordination of Accelerator Research
Jerry Nolen, Director of ATLA and Technical Director, Rare Isotope Accelerator

Jlab

Swapan Chattopadhyay, Associate Director of Accelerator

BNL

Milind Diwan, Scientist, Physics Department
Deepak Raparia, Scientist, Collider Accelerator Department

US Universities

Harry Weerts, Professor, Michigan State University
Doug Michael, Senior Research Associate, California Institute of Technology
Supriya Jain, Research Associate, Oklahoma University
Sanjib Mishra, Professor, University of South Carolina

India

Vinod Sahni, Director, Center of Advanced Technology
Dilip Bhawalkar, Ex-Director, Center of Advanced Technology
Ram Shivpuri, Professor, University of Delhi
Kirti Ranjan, Research Associate, University of Delhi

Appendix-II

Indo-US Accelerator R&D Working Group Meeting
Fermilab, Aug. 5th-6th 2004.
Hornet's Nest Conference Room, WH8X

(The meeting will be available on ESNET with ID 824877. You can join this meeting also on phone by calling 510-883-7860 and 824877#. We have tested this with Cornell, Jlab, SLAC, ANL, TIFR (India), others can also join if you have a registered node to ESNET)

Aug 5th Morning

Welcome, Hugh Montgomery, Fermilab, 10:15-10:30

Overview

- Prospect of Indo-US Collaboration, Shekhar Mishra, FNAL (10:30-11:00)
- Fermilab Accelerator R&D Plan overview, Steve Holmes, FNAL (11:00-11:30)
- SLAC Accelerator R&D Plan overview, David Burke, SLAC (11:30-12:00)
- Accelerator Activities at ANL, Kwang-Je Kim, ANL (12:00-12:30)

Working Lunch for visitors and speakers (12:30-1:30) Hosted by Steve Holmes: General Discussion

Aug 5th Afternoon

Linear Collider

- International Linear Collider R&D, Technology Options and collaboration, Steve Holmes, FNAL (2:30-3:00)

India Accelerator Activities

- Indian Accelerator Program: Present and Future, Vinod Sahni, CAT (3:00-3:30)

Break (3:30-4:00)

Simulation and Computing

- Grid Computing efforts in India, R. Shivpuri, Delhi University (4:00-4:30)
- Grid Computing at Fermilab, Vicky White, FNAL (4:30-5:00)

Indo-US Collaboration Discussion, All, (5:00-6:00)

Dinner at Chez Leon Hosted by Mike Witherell (Invited Guests)

Aug 6th

Accelerator R&D

- Proton Driver R&D and possible area of collaboration, G. W. Foster, Fermilab (11:00-11:30)
- Rare Isotope Accelerator, Jerry Nolen, ANL (11:30-12:00)

Lunch for Visitors & Speaker (12:00-1:15) hosted by Steve Holmes

Fermilab Tour (1:15 - 3:45)

- Fermilab Photo Injector Lab (Piot and Leo)
- SC Facility (Nikolay and Yuri)
- Accelerator Division Linac and MCR (Dan Johnson)
- Feynman Computing Center (Vicky White)
- CDF and D0 (Nigel, Kirti Ranjan)

Coffee (3:45-4:15)

Astrophysics

- India Gamma Ray Observatory, Vinod Sahni, (4:15-5:00)

Discussion on collaboration and future interactions (5:00-6:00)

Dinner hosted by Indian Scientist at Fermilab 7:30 P.M.-11:30 P.M.

Appendix-III

Although the full Indian delegation could not reach, the first planned meeting of the Indo-US S&T collaboration on Accelerator R&D working group was held on Aug. 5th-6th at Fermilab. Indian physicists currently participate in the D0 experiment at Fermilab. A rough count of people of Indian origin at Fermilab has yielded in 55 physicists and engineers.

We had a very successful visit to India during the Nov. 2003. A trip report of that visit was submitted to DOE. The US team was very impressed with the Indian technical ability and amount of R&D they are undertaking. Indian laboratories and industries quality looked to be at par with US.

- We had an opportunity to visit the Indus-II project at the Center of Advanced Technology (CAT). Indus-II is a 2.5 GeV synchrotron Light source built by India. The commissioning of Indus-II is going to start some time in 2005.
- India has contributed significantly to LHC. We visited the Superconducting Magnet production facility at CAT. CAT is building corrector magnets for LHC.
- India is also building detectors for CMS. India has sent several people to CERN to participate in LHC construction.
- India is contributing significantly to the LHC-CMS Grid computing project by its strong presence in IT world. Two institutions have got teir-2 status and seven institutes have been given Teir-3 status for LHC Grid computing.
- India has built two superconducting Linac boosters one at Delhi and another at Mumbai..
- India is pushing ahead to build an Indian Neutrino Observatory. Many view that this would be a world class facility and there are discussions to open this to international collaboration.
- India is planning a Gamma Ray Observatory at an altitude of 4200m and could be interested in collaboration.
- India has a vision to build other accelerators in India. In our discussions they are similar to SNS and Proton Driver with its full extension.
- India has large resources of well trained technical people.

We view the following areas where the two counties can collaborate.

- 1) Present neutrino experiment with a goal of collaboration and construction of future neutrino experiment in USA (MINOS, NOVA etc. and India (INO).
- 2) Indian scientists participating in SPEAR commissioning with a goal of US accelerator scientists participating in Indus-II commissioning.
- 3) Design and construction of new accelerator projects like Linac Coherent Light Source (SLAC), Rare Isotope Accelerator (ANL/MSU) and Super-conducting Proton Linac (Fermilab).
- 4) Developing super-conducting RF technology for accelerators (Fermilab/Cornell/Jlab).
- 5) Linear Collider design and industrial production of its hardware.
- 6) GRID computing (Fermilab).
- 7) Development of Linear Collider detector design simulation software and detector R&D.
- 8) We view that for ILC design and construction these initial collaborations on other accelerator and experiments could be the foundation.

- 9) Students and Post-doc from India can contribute in a significant way to the ongoing programs as they have done at Fermilab in past 20 years.

Appendix-II-05

[Indo-US Accelerator R&D Collaboration](#)